CHAPTER VIII
FLOW THEORY AND CAPACITY

Just as structural analysis is used to predetermine the structural stability of buried cast iron soil pipe, hydraulic analysis is used to provide an adequate flow capacity for the sewage or drainage system in which the pipe is installed. Hydraulic analysis considers the variables that govern flow capacity, including the pipe diameter, the length of the sewer or drain line, the slope of the pipe, and the roughness or smoothness of the pipe's internal surface. All of these variables affecting flow in a particular system must be analyzed so that the pipe is sized and installed to efficiently carry the maximum volume of water expected to flow through the system under peak operating conditions.

The question, "How much water will flow through a certain size" is frequently asked regarding flow capacity. Unfortunately, the inquiry mentions only one of the variables that can materially alter the flow, and more complete information on the particular installation must be obtained before an accurate and useful response can be made. It is the purpose of this chapter to review flow theory and the determination of flow capacity and thereby present practical information relating to proper hydraulic design for cast iron soil pipe waste water systems.

Flow in Sewers and Drains

Most cast iron soil pipe in sewage and drainage systems flow only partially full (i.e., free surface flow or gravity flow), and would properly be termed "open channel." Since frictional losses are generally independent of pressure, the flow of water in both full pipes and open channels is governed by the same basic laws and expressed in formulas of the same general form.[1]

The laws applying to conduit flow usually assume steady, uniform conditions, or an even distribution of liquid throughout the system. This continuity of flow, although generally not maintained over an extended period of time, is closer to the conditions likely to exist in cast iron soil pipe sewers — as opposed to those in drains, in which surge flow frequently occurs. It is customary, however, to utilize the same hydraulic principles to determine the flow in sewers and to estimate the capacities of sloping drains in and adjacent to buildings.[2]

Because the amount of suspended solids in sewage is usually too small to have more than a negligible effect on the flow pattern, the flow of sewage in a clean conduit behaves in the same manner as the flow of water, with one possible exception: namely, that sewage could conceivably cause a change in surface condition or an accumulation of slime on the inner walls of the conduit over a period of years. This would have a long-term influence on the conduit's flow, altering its

---

[1] Ernest W. Schoder and Francis M. Dawson, *Hydraulics*, 2nd edition, New York: McGraw-Hill Book Company, Inc., 1934, p. 237; Horace W. King, Chest O. Wisler and James G. Woodburn, *Hydraulics*, 5th edition, New York: John Wiley and Sons, Inc., 1948, p. 175; Horace W. King and Ernest F. Brater, *Handbook of Hydraulics for the Solution of Hydrostatic and Fluid-Flow Problems*, 5th edition, New York; McGraw-Hill Book Company, Inc., 1963, p. 6-1.

[2] Robert S. Wyly33, *A Review of the Hydraulics of Circular Sewers in Accordance with the Manning Formula*, Paper presented at 54th Annual Meeting of the American Society of Sanitary Engineering, October 9-14, 1960, Washington, D.C.: U.S. Department of Commerce, National Bureau of Standards, 1960, p.1.

pattern from that found in a comparable conduit used to carry water.[3] However, the many detergents commonly introduced into sewers tend to maintain their cleanliness, thus making water-flow measurements still applicable, even over the long term, to sewage-flow measurements in the same conduits.

Laminar Flow and Turbulent Flow

Two basic types of flow can occur in conduits used to transport fluids. The flow is termed *laminar* when the fluid moves, without eddies or cross currents, in straight lines parallel to the walls of the conduit. Once the flow velocity reaches a “critical” rate, cross currents set in causing the fluid to move through the conduit in an irregular manner, in which case the flow is said to be *turbulent*.

The Reynolds Number: The best criterion for determining the type of flow that prevails in a particular conduit under specified conditions is the Reynolds Number, conceived by Professor Osborne Reynolds of Owens College, Manchester, England and first used in 1883 to explain the flow of water in pipes.[4] Reynolds determined that that a general increase in the rate or velocity of flow eventually transforms it from laminar to turbulent and that the flow reverts back to laminar as its velocity gradually diminishes. By means of experiments using water at different temperatures this phenomenon was found to depend not only on the velocity of flow, but also on the viscosity and density of the fluid and the diameter of the pipe. Reynolds expressed it numerically as follows:

$$\frac{\text{diameter of the pipe} \times \text{velocity} \times \text{density of fluid}}{\text{viscosity of fluid}}$$

This expression, which can be written as DVp/u, is known as the *Reynolds Number*. It has no physical dimensions, It is a mere number, its value independent of the system of units (e.g., foot-second-pound) used to express its components. At low Reynolds numbers, when viscous forces are predominant, laminar flow occurs. Assuming the flow velocity is less than critical, the tendency of the fluid to wet and adhere to the pipe walls and the viscosity of its adjacent layers contributes to streamlining the flow. However, once a certain value of the Reynolds number is reached the flow turns unstable and following a brief transition period becomes clearly turbulent. Extensive testing of commercial pipe samples of circular cross section has established that for Reynolds Numbers below a value of about 2,000 laminar flow can be expected. whereas turbulent flow occurs at values above 3,000. The range between these critical numbers is referred to as the “transition zone.”[5]

---

[3] Wyly, *op cit*., p. 4.

[4] Osborne Reynolds, “An Experimental Investigation of the Circumstances which Determine Whether the Motion of Water Will Be Direct or Sinuous and the Laws of Resistance in Parallel Channels,” *Phil Trans Roy. Soc.*, London, 1993, or *Sci. Papers*, Vol. 2, p. 51.

[5] Schoder and Dawson, *op cit.*, pp. 230-232, 248-249; King, Wisler and Woodburn, *op. cit.*, pp. 175-179; J. Jennings, *The Reynolds Number*, Manchester: Emmott and Company, Ltd., 1946. pp. 5-16.

As a general rule, turbulent flow is considered to be characteristic of all but an extremely limited number of cast iron soil pipe sewage and drainage systems, since the velocity of the flow of water in almost all installations results in Reynolds Numbers above 10,000. Laminar flow, which is more akin to the flow of water in very small tubes and to the flow of oil and other viscous liquids in commercial pipe, occurs in sewers and drains only at unusually low discharge rates and slopes.[6] The predominance of turbulent flow has been established in extensive studies made by the National Bureau of Standards showing that turbulent flow occurs in 3 and 4 inch gravity drains at a slope of ¼ inch per foot for half-full or full conduit flow.

Premises Governing Flow Determination

Determination of the flow in cast iron soil pipe sewers and drains is based on the hydraulic premises discussed above, which can be restated as follows:

(1) The flow is of the open channel type with the conduit partially full and the top surface of the waste water exposed to the atmosphere.

(2) The flow is uniform with the mean velocity and depth of the waste water constant throughout the entire length of the conduit.

(3) The flow of sewage behaves in the same manner as the flow of drainage water.

(4) The flow is fully turbulent with the waste water moving through the conduit as a turbulent mass of fluid.

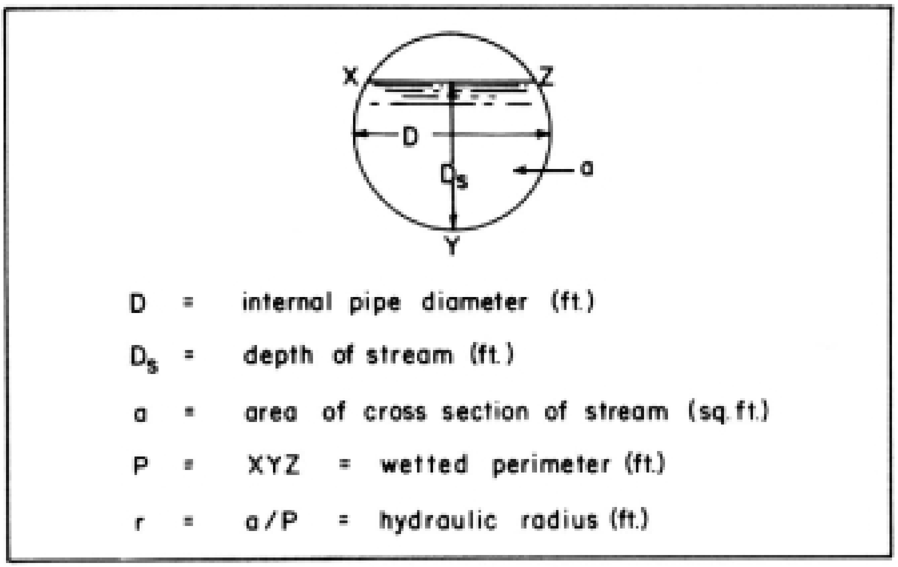
Figure 1 illustrates the cross section of a cast iron soil pipe open channel. It will be noted that the conduit is flowing only partially full with the top surface of the waste water exposed to normal atmospheric pressure. With D_S indicating the maximum depth of water in the cross section, the wetted perimeter, P, of the sewer or drain is represented by XYZ, the length of the line of contact between the wetted cross section and the surface of the channel. The hydraulic radius, r, of the sewer or drain is equal to a/P, the *cross sectional area of the stream* divided by the wetted perimeter.

Figure 2 provides a graphic representation of uniform flow in an open channel, showing the slopes of the hydraulic gradient, the energy gradient, and the invert. The *hydraulic gradient* represents the slope of the surface of the sewage or drainage water and depends on velocity head. The *energy gradient* is a graphical representation of total energy or total head, with the drop in the gradient H_f, providing a measure of lost head due to friction. The distance between the energy gradient and the hydraulic gradient indicates the total energy or velocity head, $V^2/2g$, remaining at any point along the sewer or drain line. The *invert* is a line that runs lengthwise along the base of the channel at the lowest point on its wetted perimeter, its slope established when the sewer or drain is installed.

When the flow between points 1 and 2 (in Figure 2) is uniform, then the depth, D_S, of the sewage or drainage water, the mean velocity, V, and the velocity head, $V^2/2g$, are constant throughout the entire length, L, and the slopes of the hydraulic gradient, the energy gradient and the invert are parallel.

---

[6] King, Wisler and Woodburn, *op. cit.,* p. 178; Schoder and Dawson, *op. cit.,* p. 231; Wyly, *op. cit.,* p. 2.



D = internal pipe diameter (ft.)

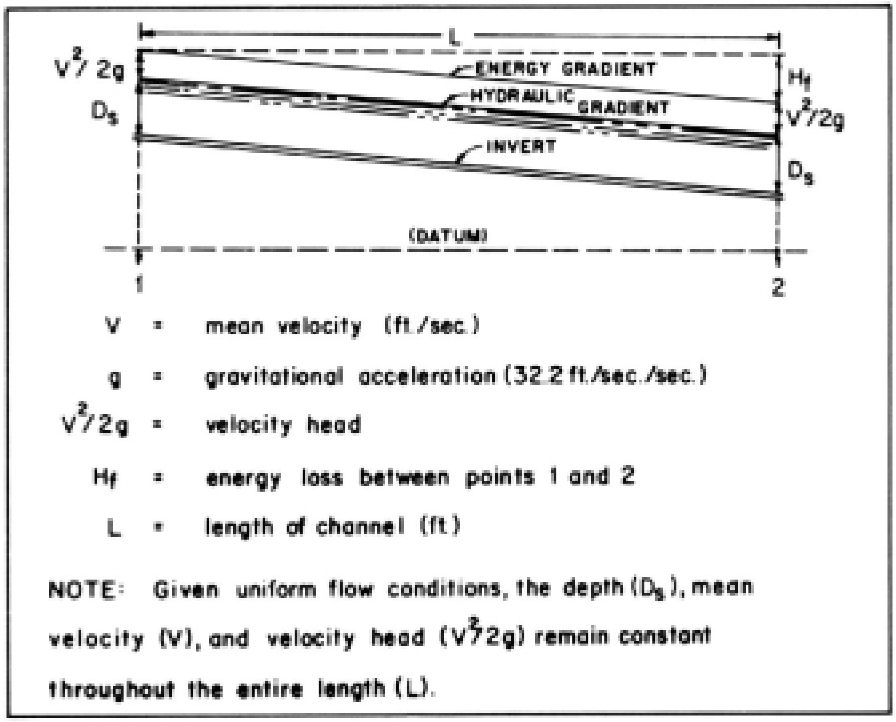
D_s = depth of stream (ft.)

a = area of cross section of stream (sq. ft.)

P = XYZ = wetted perimeter (ft.)

r = a/P = hydraulic radius (ft.)

FIG. 1 — Cross Section of Cast Iron Soil Pipe Open Channel Sewer or Drain



V = mean velocity (ft./sec.)

g = gravitational acceleration (32.2 ft./sec./sec.)

$V^2/2g$ = velocity head

H_f = energy loss between points 1 and 2

L = length of channel (ft.)

NOTE: Given uniform flow conditions, the depth (D_s), mean velocity (V), and velocity head ($V^2/2g$) remain constant throughout the entire length (L).

FIG. 2 — Uniform Flow of Open Channel Sewer or Drain

Formulas for Flow Determination

The determination of flow in a waste water system centers around the relationship between the velocity of flow and the head or energy loss that results from friction. As the flow moves through the hydraulic system, it is retarded by friction and the loss of energy (i.e., the amount of energy that must be expended to overcome frictional resistance and maintain the flow). It should be noted that the smooth inner surface of cast iron soil pipe permits an efficient use of available energy, and important factor to consider in constructing a hydraulic system.

A number of formulas have been developed relating the velocity of flow and the loss of energy due to friction. The most prominent of these with application to open channel hydraulics was introduced by Manning (1890).

The Manning Formula: The Irish engineer, Robert Manning, in 1890 proposed the following equation for friction-controlled flow:[7]

$$\mathbf{V = \frac{1.486}{n} r^{2/3} s^{1/2}} \tag{1}$$

Over the years, the Manning formula has become widely recognized. It is the only empirical type of energy -loss formula that is extensively used to determine fully-turbulent, open channel flow. Among its advantages are the availability of numerous test results for establishing values of n, and its inclusion of the hydraulic radius, which makes it adaptable to flow determination in conduits of various shapes.[8] The Manning formula, written in terms of discharge rate (Formula 2), has been employed in the remainder of this chapter to determine the flow capacity of cast iron soil pipe. Its derivation requires that both sides of Formula 1 be multiplied by the area of the cross section of the stream.

$$\mathbf{Q = \frac{1.486}{n} ar^{2/3} s^{1/2}} \tag{2}$$

where
Q = aV = discharge rate (cu. ft./sec.)
a = area of cross section of stream (sq. ft.)
r = roughness coefficient

Roughness Coefficient: Values of the roughness coefficient, n, in the Manning formula have been determined experimentally for various conduit materials, and a value of n = 0.012 is recommended for use in designing cast iron soil pipe hydraulic systems. Although lower, more favorable values of the coefficient are commonly obtained in controlled tests, particularly when coated pipe is used, the recommended value considers the possibility that bends and branch connections in an actual system may retard the flow.

Self-Cleansing Velocities: Table 1 is provided to assist in the design of cast iron soil pipe sanitary systems. It indicates the slopes required to obtain self-cleansing or scouring velocities at var-

---

[7] Robert Manning, "Flow of Water in Open Channels and Pipes," *Trans. Inst. Civil Engrs.,* Vol. 20, Ireland, 1890.

[8] King and Grater, *op. cit.,* pp. 6-16, 7-10 and 7-13.

ious rates of discharge. A *self-cleansing velocity*, or one sufficient to carry sewage solids along the conduit, permits the system to operate efficiently and reduces the likelihood of stoppages. A minimum velocity of 2 feet per second is the generally prescribed norm consistent with the removal of sewage solids, but a velocity of 2.5 feet per second can be used in cases where an additional degree of safety is desired.

In addition to designing self-cleaning velocities into sanitary sewers, it is considered good practice to impose an upper velocity limit of 10 feet per second in both sewers and drains. This restricts the abrasive action of sand and grit that may be carried through the system. However, because cast iron soil pipe is highly resistant to abrasion, it is most suitable for use where high velocity operation cannot be avoided.

Flow Capacity of Cast Iron Soil Pipe Sewers and Drains

The velocity and flow in cast iron soil pipe sewers and drains, computed by means of the Manning formula (Formula 2), are indicated in Table 2 and in Charts 1 through 4 inclusive. Flow capacities are provided for systems using pipe sizes 2 through 15 inches, installed at a full range of slopes from 0.0010 to 0.10 ft/ft and pipe fullness of one-quarter, one-half, three-quarters, and full. Both Table 2 and the flow diagrams are based on the value 0.012 for n, the roughness coefficient, and on the internal pipe diameters specified by ASTM A74.

Although Formula 2 expresses the flow or discharge in cubic feet per second, flow in cast iron soil pipe is commonly measured in gallons per minute, and consequently, the formula results have been multiplied by the conversion factor 448.86 (60 sec./min. x 7.481 gal./cu./ft.) to obtain the capacities indicated.

TABLE 1
Slopes of Cast Iron Soil Pipe Sanitary Sewers Required to Obtain Self-Cleaning Velocities of 2.0 and 2.5 Ft./Sec.
(Based on Mannings Formula with N = .012)

		¼ FULL		½ FULL		¾ FULL		FULL	
Pipe Size (In.)	**Velocity (Ft./Sec.)**	**Slope (Ft./Ft.)**	**Flow (Gal./Min.)**	**Slope (Ft./Ft.)**	**Flow (Gal./Min.)**	**Slope (Ft./Ft.)**	**Flow (Gal./Min.)**	**Slope (Ft./Ft.)**	**Flow (Gal./Min.)**
2.0	2.0	0.0313	4.67	0.0186	9.34	0.0148	14.09	0.0186	18.76
	2.5	0.0489	5.84	0.0291	11.67	0.0231	17.62	0.0291	23.45
3.0	2.0	0.0178	10.77	0.0107	21.46	0.0085	32.23	0.0107	42.91
	2.5	0.0278	13.47	0.0167	26.82	0.0133	40.29	0.0167	53.64
4.0	2.0	0.0122	19.03	0.0073	38.06	0.0058	57.01	0.0073	76.04
	2.5	0.0191	23.79	0.0114	47.58	0.0091	71.26	0.0114	95.05
5.0	2.0	0.0090	29.89	0.0054	59.79	0.0043	89.59	0.0054	119.49
	2.5	0.0141	37.37	0.0085	74.74	0.0067	11.99	0.0085	149.36
6.0	2.0	0.0071	43.18	0.0042	86.36	0.0034	129.54	0.0042	172.72
	2.5	0.0111	53.98	0.0066	107.95	0.0053	161.93	0.0066	214.90
8.0	2.0	0.0048	77.20	0.0029	154.32	0.0023	231.52	0.0029	308.64
	2.5	0.0075	96.50	0.0045	192.90	0.0036	289.40	0.0045	385.79
10.0	2.0	0.0036	120.92	0.0021	241.85	0.0017	362.77	0.0021	483.69
	2.5	0.0056	151.15	0.0033	302.31	0.0026	453.46	0.0033	604.61
12.0	2.0	0.0028	174.52	0.0017	349.03	0.0013	523.55	0.0017	698.07
	2.5	0.0044	218.15	0.0026	436.29	0.0021	654.44	0.0026	872.58
15.0	2.0	0.0021	275.42	0.0012	550.84	0.0010	826.26	0.0012	1101.68
	2.5	0.0032	344.28	0.0019	688.55	0.0015	1032.83	0.0019	1377.10

TABLE 2
Velocity and Flow in Cast Iron Soil Pipe Sewers and Drains
(Based on Mannings Formula with N = .012)

Pipe Size (In.)	SLOPE		¼ FULL		½ FULL		¾ FULL		FULL	
	(In./Ft.)	(Ft./Ft.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)
2.0	0.0120	0.0010	0.36	0.83	0.46	2.16	0.52	3.67	0.46	4.35
	0.0240	0.0020	0.51	1.18	0.66	3.06	0.74	5.18	0.66	6.15
	0.0360	0.0030	0.62	1.45	0.80	3.75	0.90	6.35	0.80	7.53
	0.0480	0.0040	0.72	1.67	0.93	4.33	1.04	7.33	0.93	8.69
	0.0600	0.0050	0.80	1.87	1.04	4.84	1.16	8.20	1.04	9.72
	0.0720	0.0060	0.88	2.04	1.13	5.30	1.27	8.98	1.13	10.65
	0.0840	0.0070	0.95	2.21	1.23	5.72	1.38	9.70	1.23	11.50
	0.0960	0.0080	1.01	2.36	1.31	6.12	1.47	10.37	1.31	12.29
	0.1080	0.0090	1.07	2.50	1.39	6.49	1.56	11.00	1.39	13.04
	0.1200	0.0100	1.13	2.64	1.47	6.84	1.64	11.59	1.47	13.75
	0.2400	0.0200	1.60	3.73	2.07	9.67	2.33	16.39	2.07	19.44
	0.3600	0.0300	1.96	4.57	2.54	11.85	2.85	20.07	2.54	23.81
	0.4800	0.0400	2.26	5.28	2.93	13.68	3.29	23.18	2.93	27.49
	0.6000	0.0500	2.53	5.90	3.28	15.29	3.68	25.92	3.28	30.74
	0.7200	0.0600	2.77	6.47	3.59	16.75	4.03	28.39	3.59	33.67
	0.8400	0.0700	2.99	6.98	3.88	18.10	4.35	30.66	3.88	36.37
	0.9600	0.0800	3.20	7.47	4.14	19.35	4.65	32.78	4.14	38.88
	1.0800	0.0900	3.39	7.92	4.40	20.52	4.93	34.77	4.40	41.24
	1.2000	0.1000	3.58	8.35	4.63	21.63	5.20	36.65	4.63	43.47
3.0	0.0120	0.0010	0.47	2.55	0.61	6.56	0.69	11.05	0.61	13.12
	0.0240	0.0020	0.67	3.61	0.86	9.28	0.97	15.63	0.86	18.55
	0.0360	0.0030	0.82	4.42	1.06	11.36	1.19	19.14	1.06	22.72
	0.0480	0.0040	0.95	5.11	1.22	13.12	1.37	22.10	1.22	26.24
	0.0600	0.0050	1.06	5.71	1.37	14.67	1.53	24.71	1.37	29.33
	0.0720	0.0060	1.16	6.25	1.50	16.07	1.68	27.07	1.50	32.13
	0.0840	0.0070	1.25	6.75	1.62	17.35	1.81	29.24	1.62	34.71
	0.0960	0.0080	1.34	7.22	1.73	18.55	1.94	31.26	1.73	37.11
	0.1080	0.0090	1.42	7.66	1.83	19.68	2.06	33.16	1.83	39.36
	0.1200	0.0100	1.50	8.07	1.93	20.74	2.17	34.95	1.93	41.49
	0.2400	0.0200	2.21	11.42	2.73	29.33	3.07	49.43	2.73	58.67
	0.3600	0.0300	2.60	13.98	3.35	35.93	3.76	60.53	3.35	71.86
	0.4800	0.0400	3.00	16.14	3.87	41.49	4.34	69.90	3.87	82.97
	0.6000	0.0500	3.35	18.05	4.32	46.38	4.85	78.15	4.32	92.77
	0.7200	0.0600	3.67	19.77	4.74	50.81	5.31	85.61	4.74	101.62
	0.8400	0.0700	3.96	21.36	5.12	54.88	5.74	92.47	5.12	109.76
	0.9600	0.0800	4.24	22.83	5.47	58.67	6.13	98.85	5.47	117.34
	1.0800	0.0900	4.50	24.22	5.80	62.23	6.51	104.85	5.80	124.46
	1.2000	0.1000	4.74	25.53	6.11	65.29	6.86	110.52	6.11	131.19

TABLE 2 – (Continued)

Velocity and Flow in Cast Iron Soil Pipe Sewers and Drains
(Based on Mannings Formula with N = .012)

Pipe Size (In.)	SLOPE		¼ FULL		½ FULL		¾ FULL		FULL	
	(In./Ft.)	(Ft./Ft.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)
4.0	0.0120	0.0010	0.57	5.45	0.74	14.08	0.83	23.63	0.74	28.12
	0.0240	0.0020	0.81	7.70	1.05	19.91	1.17	33.42	1.05	39.77
	0.0360	0.0030	0.99	9.44	1.28	24.38	1.44	40.92	1.28	48.71
	0.0480	0.0040	1.15	10.90	1.48	28.16	1.66	47.26	1.48	56.25
	0.0600	0.0050	1.28	12.18	1.65	31.48	1.85	52.83	1.65	62.88
	0.0720	0.0060	1.40	13.34	1.81	34.48	2.03	57.88	1.81	68.89
	0.0840	0.0070	1.51	14.41	1.96	37.25	2.19	62.51	1.96	74.41
	0.0960	0.0080	1.62	15.41	2.09	39.82	2.34	66.83	2.09	79.54
	0.1080	0.0090	1.72	16.34	2.22	42.23	2.49	70.88	2.22	84.37
	0.1200	0.0100	1.81	17.23	2.34	44.52	2.62	74.72	2.34	88.93
	0.2400	0.0200	2.56	24.36	3.31	62.96	3.71	105.67	3.31	125.77
	0.3600	0.0300	3.14	29.84	4.05	77.11	4.54	129.42	4.05	154.04
	0.4800	0.0400	3.62	34.46	4.68	89.04	5.24	149.44	4.68	177.86
	0.6000	0.0500	4.05	38.52	5.23	99.55	5.86	167.08	5.23	198.86
	0.7200	0.0600	4.43	42.20	5.73	109.05	6.42	183.02	5.73	217.84
	0.8400	0.0700	4.79	45.58	6.19	117.79	6.94	197.69	6.19	235.29
	0.9600	0.0800	5.12	48.73	6.62	125.92	7.41	211.34	6.62	251.54
	1.0800	0.0900	5.43	51.68	7.02	133.56	7.86	224.15	7.02	266.80
	1.2000	0.1000	5.73	54.48	7.40	140.78	8.29	236.28	7.40	281.23
5.0	0.0120	0.0010	0.67	9.94	0.86	25.71	0.96	43.15	0.86	51.37
	0.0240	0.0020	0.94	14.06	1.22	36.35	1.36	61.02	1.22	72.65
	0.0360	0.0030	1.15	17.22	1.49	44.52	1.67	74.74	1.49	88.98
	0.0480	0.0040	1.33	19.88	1.72	51.41	1.93	86.30	1.72	102.75
	0.0600	0.0050	1.49	22.23	1.92	57.48	2.15	96.49	1.92	114.87
	0.0720	0.0060	1.63	24.35	2.11	62.97	2.36	105.70	2.11	125.84
	0.0840	0.0070	1.76	26.30	2.28	68.01	2.55	114.17	2.28	135.92
	0.0960	0.0080	1.88	28.12	2.43	72.71	2.72	122.05	2.43	145.31
	0.1080	0.0090	2.00	29.82	2.58	77.12	2.89	129.45	2.58	154.12
	0.1200	0.0100	2.10	31.44	2.72	81.29	3.05	136.45	2.72	162.46
	0.2400	0.0200	2.97	44.46	3.85	114.96	4.31	192.97	3.85	229.75
	0.3600	0.0300	3.64	54.45	4.71	140.80	5.28	236.34	4.71	281.38
	0.4800	0.0400	4.21	62.88	5.44	162.58	6.09	272.91	5.44	324.91
	0.6000	0.0500	4.70	70.30	6.08	181.77	6.81	305.12	6.08	363.26
	0.7200	0.0600	5.15	77.01	6.66	199.12	7.46	334.24	6.66	397.94
	0.8400	0.0700	5.56	83.18	7.19	215.07	8.06	361.02	7.19	429.82
	0.9600	0.0800	5.95	88.92	7.69	229.92	8.62	385.95	7.69	459.50
	1.0800	0.0900	6.31	94.31	8.16	243.92	9.14	409.36	8.16	487.37
	1.2000	0.1000	6.65	99.42	8.60	257.06	9.63	431.50	8.60	513.73

TABLE 2 – (Continued)

Velocity and Flow in Cast Iron Soil Pipe Sewers and Drains

(Based on Mannings Formula with N = .012)

Pipe Size (In.)	SLOPE		¼ FULL		½ FULL		¾ FULL		FULL	
	(In./Ft.)	(Ft./Ft.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)
6.0	0.0120	0.0010	0.75	16.23	0.97	41.98	1.09	70.55	0.97	83.96
	0.0240	0.0020	1.06	22.95	1.37	59.37	1.54	99.77	1.37	118.74
	0.0360	0.0030	1.30	28.11	1.68	72.71	1.89	122.20	1.68	145.42
	0.0480	0.0040	1.50	32.46	1.94	83.96	2.18	141.10	1.94	167.92
	0.0600	0.0050	1.68	36.29	2.17	93.87	2.44	157.76	2.17	187.74
	0.0720	0.0060	1.84	39.75	2.38	102.83	2.67	172.81	2.38	205.66
	0.0840	0.0070	1.99	42.94	2.57	111.07	2.88	186.66	2.57	222.13
	0.0960	0.0080	2.13	45.90	2.75	118.74	3.08	199.55	2.75	237.47
	0.1080	0.0090	2.26	48.69	2.92	125.94	3.27	211.65	2.92	251.88
	0.1200	0.0100	2.38	51.32	3.07	132.75	3.44	223.10	3.07	265.50
	0.2400	0.0200	3.36	72.58	4.35	187.74	4.87	315.51	4.35	375.47
	0.3600	0.0300	4.12	88.89	5.32	229.93	5.97	386.42	5.32	459.86
	0.4800	0.0400	4.75	102.64	6.15	265.50	6.89	446.20	6.15	531.00
	0.6000	0.0500	5.32	114.76	6.87	296.84	7.70	498.87	6.87	593.68
	0.7200	0.0600	5.82	125.71	7.53	325.17	8.44	546.27	7.53	650.34
	0.8400	0.0700	6.29	135.78	8.13	351.22	9.11	590.27	8.13	702.45
	0.9600	0.0800	6.72	145.16	8.70	375.47	9.74	631.02	8.70	750.95
	1.0800	0.0900	7.13	153.96	9.22	398.25	10.33	669.30	9.22	796.50
	1.2000	0.1000	7.52	162.29	9.72	419.79	10.89	705.51	9.72	839.59
8.0	0.0120	0.0010	0.91	35.25	1.18	91.04	1.32	153.06	1.18	182.09
	0.0240	0.0020	1.29	49.85	1.67	128.75	1.87	216.46	1.67	257.51
	0.0360	0.0030	1.58	61.05	2.04	157.69	2.29	265.11	2.04	315.38
	0.0480	0.0040	1.83	70.50	2.36	182.09	2.64	306.12	2.36	364.17
	0.0600	0.0050	2.04	78.82	2.64	203.58	2.96	342.26	2.64	407.16
	0.0720	0.0060	2.24	86.34	2.89	223.01	3.24	374.92	2.89	446.02
	0.0840	0.0070	2.42	93.26	3.12	240.88	3.50	404.96	3.12	481.75
	0.0960	0.0080	2.58	99.70	3.34	257.51	3.74	432.92	3.34	515.02
	0.1080	0.0090	2.74	105.75	3.54	273.13	3.97	459.18	3.54	546.26
	0.1200	0.0100	2.89	111.47	3.73	287.90	4.18	484.02	3.73	575.81
	0.2400	0.0200	4.08	157.64	5.28	407.16	5.91	684.51	5.28	814.32
	0.3600	0.0300	5.00	193.06	6.46	498.66	7.24	838.35	6.46	997.33
	0.4800	0.0400	5.78	222.93	7.46	575.81	8.36	968.05	7.46	1151.62
	0.6000	0.0500	6.46	249.24	8.34	643.77	9.35	1082.31	8.34	1287.55
	0.7200	0.0600	7.07	273.03	9.14	705.22	10.24	1185.61	9.14	1410.44
	0.8400	0.0700	7.64	294.91	9.87	761.72	11.06	1280.60	9.87	1523.45
	0.9600	0.0800	8.17	315.27	10.55	814.31	11.83	1369.02	10.55	1628.63
	1.0800	0.0900	8.66	334.40	11.19	863.71	12.54	1452.07	11.19	1727.42
	1.2000	0.1000	9.13	352.48	11.80	910.43	13.22	1530.61	11.80	1820.86

TABLE 2 – (Continued)
Velocity and Flow in Cast Iron Soil Pipe Sewers and Drains
(Based on Mannings Formula with N = .012)

Pipe Size (In.)	SLOPE		¼ FULL		½ FULL		¾ FULL		FULL	
	(In./Ft.)	(Ft./Ft.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)
10.0	0.0120	0.0010	1.06	64.08	1.37	165.75	1.54	278.56	1.37	331.51
	0.0240	0.0020	1.50	90.62	1.94	234.41	2.17	393.95	1.94	468.83
	0.0360	0.0030	1.84	110.99	2.37	287.10	2.66	482.48	2.37	574.19
	0.0480	0.0040	2.12	128.16	2.74	331.51	3.07	557.12	2.74	663.02
	0.0600	0.0050	2.37	143.29	3.07	370.64	3.43	622.88	3.07	741.28
	0.0720	0.0060	2.60	156.96	3.36	406.01	3.76	682.33	3.36	812.03
	0.0840	0.0070	2.80	169.54	3.63	438.55	4.06	737.01	3.63	877.09
	0.0960	0.0080	3.00	181.24	3.88	468.82	4.34	787.89	3.88	937.65
	0.1080	0.0090	3.18	192.24	4.11	497.26	4.61	835.69	4.11	994.53
	0.1200	0.0100	3.35	202.64	4.33	524.16	4.86	880.89	4.33	1048.32
	0.2400	0.0200	4.74	286.57	6.13	741.28	6.87	1245.77	6.13	1482.55
	0.3600	0.0300	5.80	350.98	7.51	907.88	8.41	1525.75	7.51	1815.75
	0.4800	0.0400	6.70	405.27	8.67	1048.32	9.71	1761.78	8.67	2096.65
	0.6000	0.0500	7.49	453.11	9.69	1172.06	10.86	1969.73	9.69	2344.13
	0.7200	0.0600	8.21	496.36	10.62	1283.93	11.90	2157.74	10.62	2567.86
	0.8400	0.0700	8.87	536.12	11.47	1386.80	12.85	2330.62	11.47	2773.61
	0.9600	0.0800	9.48	573.14	12.26	1482.55	13.74	2491.54	12.26	2965.11
	1.0800	0.0900	10.05	607.91	13.00	1572.49	14.57	2642.67	13.00	3144.97
	1.2000	0.1000	10.60	640.79	13.71	1657.55	15.36	2785.62	13.71	3315.09
12.0	0.0120	0.0010	1.20	104.53	1.55	270.34	1.74	454.27	1.55	540.68
	0.0240	0.0020	1.69	147.83	2.19	382.32	2.45	642.43	2.19	764.63
	0.0360	0.0030	2.07	181.05	2.68	468.24	3.01	786.82	2.68	936.48
	0.0480	0.0040	2.40	209.06	3.10	540.68	3.47	908.54	3.10	1081.35
	0.0600	0.0050	2.68	233.74	3.46	604.49	3.88	1015.78	3.46	1208.99
	0.0720	0.0060	2.93	256.05	3.79	662.19	4.25	1112.73	3.79	1324.38
	0.0840	0.0070	3.17	276.56	4.10	715.25	4.59	1201.88	4.10	1430.50
	0.0960	0.0080	3.39	295.66	4.38	764.63	4.91	1284.87	4.38	1529.27
	0.1080	0.0090	3.59	313.59	4.65	811.01	5.21	1362.81	4.65	1622.03
	0.1200	0.0100	3.79	330.56	4.90	854.88	5.49	1436.53	4.90	1709.77
	0.2400	0.0200	5.36	467.48	6.93	1208.99	7.76	2031.55	6.93	2417.98
	0.3600	0.0300	6.56	572.54	8.48	1480.71	9.50	2488.14	8.48	2961.41
	0.4800	0.0400	7.58	661.11	9.80	1709.77	10.98	2873.05	9.80	3419.54
	0.6000	0.0500	8.47	739.14	10.95	1911.58	12.27	3212.17	10.95	3823.17
	0.7200	0.0600	9.28	809.69	12.00	2094.03	13.44	3518.76	12.00	4188.07
	0.8400	0.0700	10.02	874.57	12.96	2261.81	14.52	3800.69	12.96	4523.63
	0.9600	0.0800	10.71	934.95	13.86	2417.98	15.52	4063.11	13.86	4835.96
	1.0800	0.0900	11.36	991.67	14.70	2564.65	16.46	4309.57	14.70	5129.30
	1.2000	0.1000	11.98	1045.31	15.49	2703.38	17.35	4542.69	15.49	5406.76

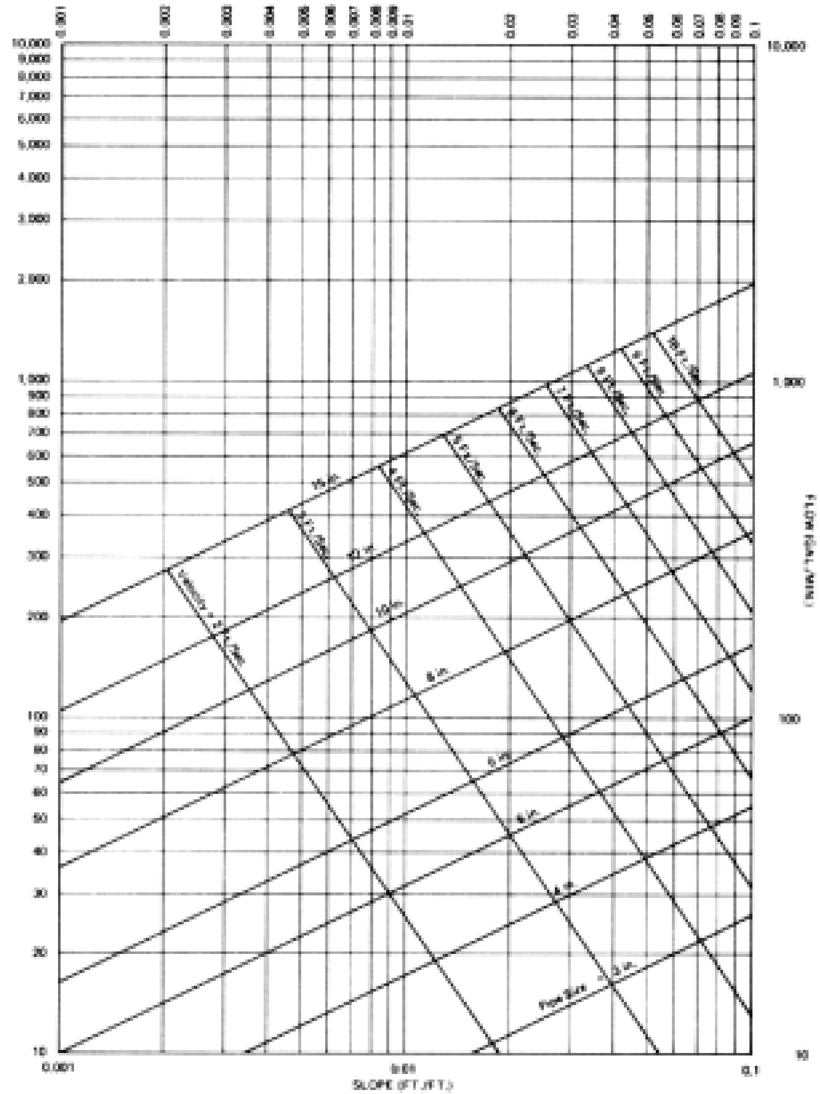
TABLE 2 – (Continued)

Velocity and Flow in Cast Iron Soil Pipe Sewers and Drains
(Based on Mannings Formula with N = .012)

Pipe Size (In.)	SLOPE		¼ FULL		½ FULL		¾ FULL		FULL	
	(In./Ft.)	(Ft./Ft.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)	Velocity (Ft./Sec.)	Flow (Gal./Min.)
15.0	0.0120	0.0010	1.39	192.03	1.80	496.67	2.02	834.85	1.80	993.34
	0.0240	0.0020	1.97	271.58	2.55	702.40	2.86	1180.65	2.55	1404.79
	0.0360	0.0030	2.42	332.61	3.12	860.25	3.50	1445.99	3.12	1720.51
	0.0480	0.0040	2.79	384.07	3.61	993.34	4.04	1669.69	3.61	1986.67
	0.0600	0.0050	3.12	429.40	4.03	1110.58	4.52	1866.77	4.03	2221.17
	0.0720	0.0060	3.42	470.38	4.42	1216.58	4.95	2044.95	4.42	2433.17
	0.0840	0.0070	3.69	508.07	4.77	1314.06	5.35	2208.79	4.77	2628.12
	0.0960	0.0080	3.94	543.15	5.10	1404.79	5.72	2361.30	5.10	2809.58
	0.1080	0.0090	4.18	576.10	5.41	1490.01	6.06	2504.54	5.41	2980.01
	0.1200	0.0100	4.41	607.26	5.70	1570.60	6.39	2640.01	5.70	3141.21
	0.2400	0.0200	6.24	858.80	8.06	2221.17	9.04	3733.54	8.06	4442.34
	0.3600	0.0300	7.64	1051.81	9.88	2720.37	11.07	4572.64	9.88	5440.73
	0.4800	0.0400	8.82	1214.52	11.41	3141.21	12.78	5280.03	11.41	6282.41
	0.6000	0.0500	9.86	1357.88	12.75	3511.98	14.29	5903.25	12.75	7023.95
	0.7200	0.0600	10.80	1487.48	13.97	3847.18	15.65	6466.69	13.97	7694.35
	0.8400	0.0700	11.67	1606.66	15.09	4155.43	16.91	6984.82	15.09	8310.85
	0.9600	0.0800	12.47	1717.60	16.13	4442.33	18.07	7467.07	16.13	8884.66
	1.0800	0.0900	13.23	1821.78	17.11	4711.80	19.17	7920.03	17.11	9423.61
	1.2000	0.1000	13.94	1920.33	18.03	4966.68	20.21	8348.44	18.03	9933.35

CHART 1
VELOCITY AND FLOW IN CAST IRON SOIL PIPE SEWERS AND DRAINS
(BASED ON MANNING'S FORMULA WITH n = .012)

*ONE-QUARTER FULL**



*Flow for 2 in. pipe size is less than 10 GPM at slopes indicated.

CHART 2

VELOCITY AND FLOW IN CAST IRON SOIL PIPE SEWERS AND DRAINS

(BASED ON MANNING'S FORMULA WITH n = .012)

ONE-HALF FULL

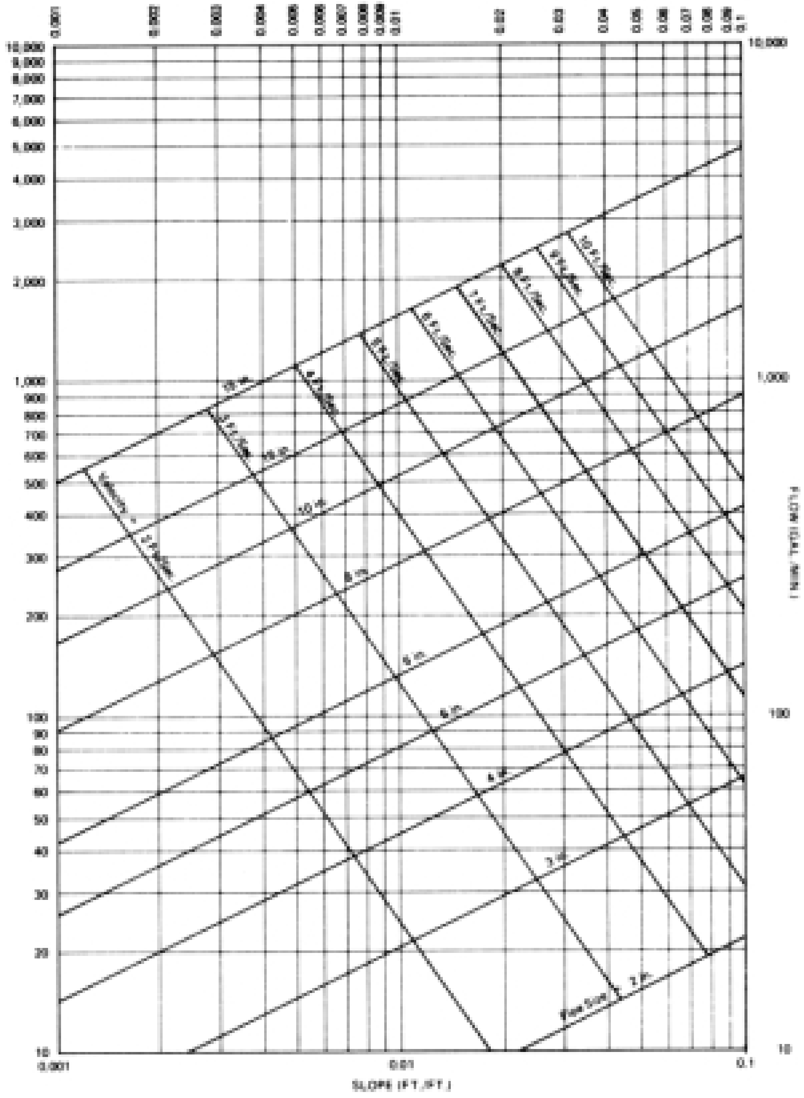


CHART 3

VELOCITY AND FLOW IN CAST IRON SOIL PIPE SEWERS AND DRAINS

(BASED ON MANNING'S FORMULA WITH n = .012)

THREE-QUARTERS FULL

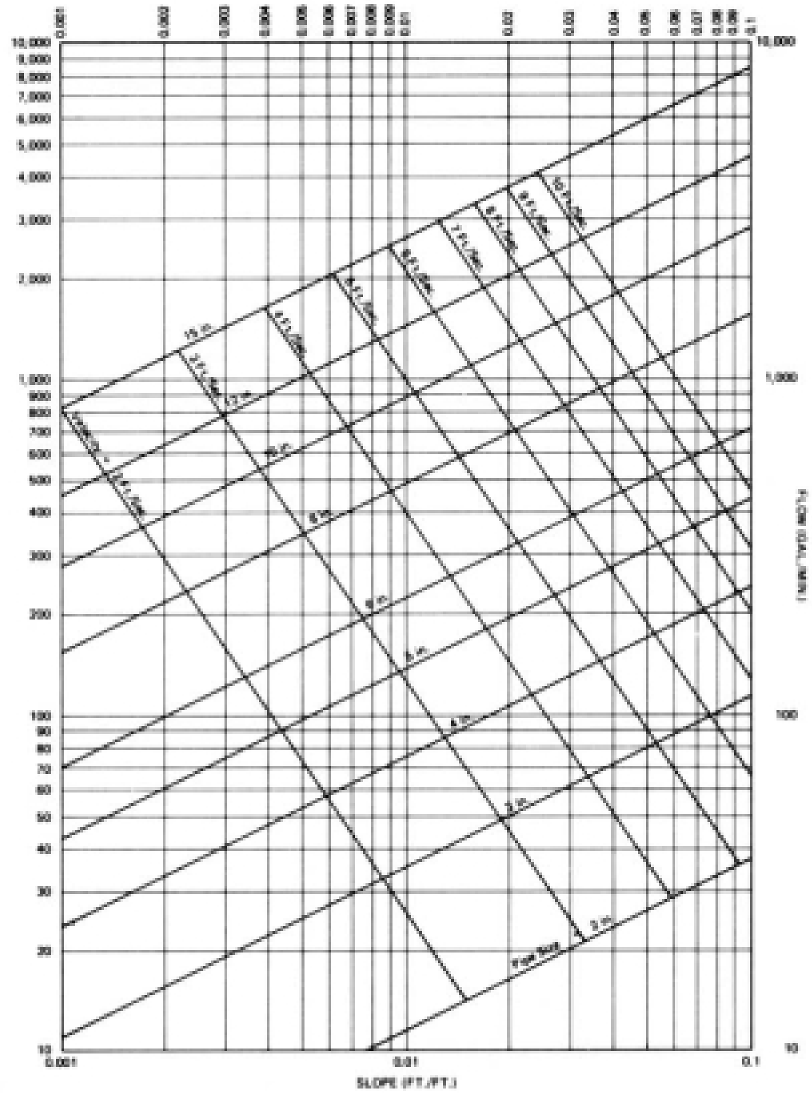
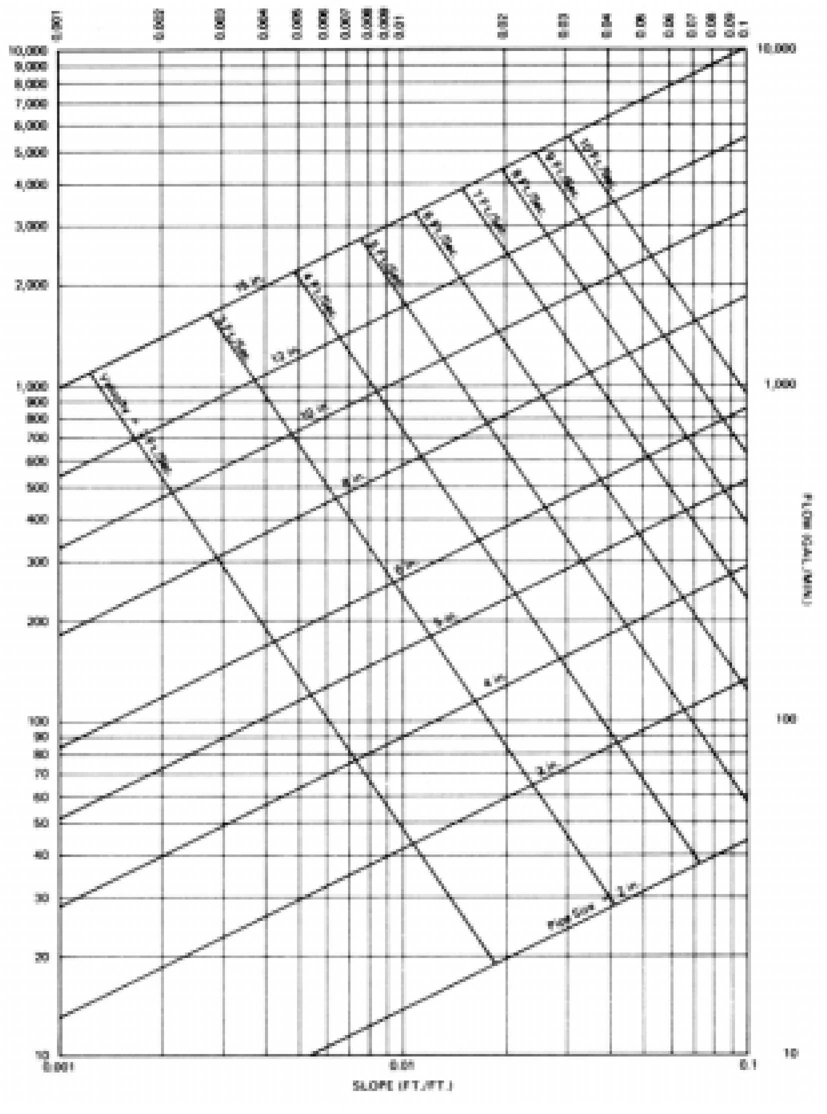


CHART 4

VELOCITY AND FLOW IN CAST IRON SOIL PIPE SEWERS AND DRAINS

(BASED ON MANNING'S FORMULA WITH n = .012)

FULL FLOW



Design of Sewers and Drains

Formula 2, Table 2, and Charts 1 through 4 provide means to insure that cast iron soil pipe is adequately sized to accommodate the expected peak flow at a designed, self-cleansing velocity. The peak flow that governs design is that projected to occur in the future during the service life of the particular system.

The factors affecting peak flow vary with the type of system to be installed. In a sanitary sewer for domestic waste, the maximum quantity of sewage depends primarily upon the density and distribution of the population and its per capita use of water. In a sewer for commercial and industrial waste, it depends on the number and type of businesses to be serviced by the system. The peak load in a storm sewer, on the other hand, is determined by the duration and intensity of rainfall and the extent, condition and slope of streets and other areas requiring drainage.

For a particular hydraulic system, the factors affecting peak flow are analyzed by means of procedures in design handbooks. Unfortunately, this analysis is generally imperfect from the standpoint of system design. In most cases, current peak flow can be accurately quantified, but only a rough approximation can be made of future peak flow, which is usually based on population trends and area development over a period of fifty or so years. This requires that provision be made for any unforeseen increase in runoff, and therefore, cast iron soil pipe hydraulic systems are most frequently designed for half-full operation at probable future peak flow. Greater or less than half-full operation can be employed, depending on design requirements and the relative accuracy with which future flow can be forecast.

Information useful in computing flow capacities by Formula 2 is presented in Tables 3, 4, and 5. Table 3 lists values for the internal diameter of the pipe, the area of the cross section of the stream, the wetted perimeter, and the hydraulic radius. Tables 4 and 5 provide numbers to the two-thirds and one-half powers.

The following example illustrates a typical computation involving the flow capacity of a cast iron soil pipe hydraulic system:

Example

An industrial plant site is to be serviced by a cast iron soil pipe sewer that must provide a flow capacity of 1,500 gallons per minute when operating half-full. This is the peak runoff that the plant is expected to generate in the future at projected maximum levels of production. Based on the grade and condition of the ground surface under which the sewer is to be installed, as well as the location of subsurface obstructions, a system slope of 0.01 ft./ft. is planned. Initially, a 15 inch pipe size is assumed, and it must be determined whether or not this will result in an adequate flow capacity, as well as an efficient operating velocity.

Given:

n = 0.012
D = 1.2500 ft. (See Table 3)
a = 0.6136 sq. ft. (See Table 3)
P = 1.9635 ft. (See Table 3)
r = a/P = 0.3125 ft. (See Table 3)
s = 0.01 ft./ft.

Solution

$$Q = \frac{1.486}{n} ar^{2/3} s^{1/2} \qquad \text{(Manning Formula – 12)}$$

$$Q = \frac{1.486}{0.012} (0.6136)\,(0.3125^{2/3})\ 0.01^{1/2}$$

$$Q = 123.833\ (0.6136)\,(0.4605)\ 0.10$$

$$Q = 123.833\ (0.282563)\ 0.10$$

$$Q = 3.4991 \text{ cu. ft./sec.}$$

$$\text{GPM} = Q \times 7.481 \text{ Gal. per cu. ft.} \times 60 \text{ seconds} = 1570.60 \text{ gal./min.}$$

This indicates that the pipe is adequately sized to provide a capacity (Q) of 1,500 gal./min. with the system flowing half-full.

In order to determine whether the system will operate at a velocity consistent with good design (i.e., between 2 and 10 ft./sec.), the following calculation is made:

V = Q/a
V = 3.4991/0.6136
V = 5.70 ft./sec.

Therefore, the system design provides both an adequate capacity and an efficient operating velocity.

The derivations of flow capacity and velocity made above by Formula 2 could have been obtained by referring to Table 2 or Chart 2. It will be noted that a number of possible designs frequently can be employed to satisfy a given capacity requirement, provided conditions at the construction site permit the designer latitude in selecting a system slope. The combination of pipe size and slope selected should most closely satisfy the capacity specified for the system and, if possible, also provide an efficient operating velocity.

TABLE 3

Variables Required to Solve Manning's Formula for Computing Flow Capacities of Cast Iron Soil Pipe Sewers and Drains

Pipe Size (in.)		1/4 Full			1/2 Full			3/4 Full			Full		
	D	a	P	r	a	P	r	a	P	r	a	P	r
2	0.1633	0.0052	0.1886	0.0276	0.0104	0.2565	0.0407	0.0157	0.3244	0.0484	0.0209	0.5130	0.0407
3	0.2466	0.0120	0.2848	0.0421	0.0239	0.3874	0.0617	0.0359	0.4899	0.0733	0.0478	0.7747	0.0617
4	0.3283	0.0212	0.3792	0.0559	0.0424	0.5157	0.0821	0.0635	0.6522	0.0974	0.0847	1.0314	0.0821
5	0.4116	0.0333	0.4754	0.0700	0.0666	0.6466	0.1029	0.0998	0.8177	0.1220	0.1331	1.2931	0.1029
6	0.4950	0.0481	0.5717	0.0841	0.0962	0.7776	0.1237	0.1443	0.9834	0.1467	0.1924	1.5551	0.1237
8	0.6616	0.0860	0.7641	0.1126	0.1718	1.0393	0.1654	0.2579	1.3144	0.1962	0.3438	2.0785	0.1654
10	0.8283	0.1347	0.9567	0.1408	0.2694	1.3011	0.2071	0.4041	1.6455	0.2456	0.5388	2.6022	0.2071
12	0.9950	0.1944	1.1492	0.1692	0.3888	1.5630	0.2488	0.5832	1.9767	0.2950	0.7776	3.1259	0.2488
15	1.2500	0.3068	1.4438	0.2125	0.6136	1.9635	0.3125	0.9204	2.4832	0.3707	1.2272	3.9270	0.3125

D = internal pipe diameter (ft.)
a = area of cross section of stream (sq. ft.)
P = wetted perimeter (ft.)
r = a/P = hydraulic radius (ft.)

TABLE 4

Numbers to the Two-Thirds Power Used to Obtain $r^{2/3}$ in Manning's Formula

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.046	.074	.097	.117	.136	.153	.170	.186	.201
.1	.215	.229	.243	.256	.269	.282	.295	.307	.319	.331
.2	.342	.353	.364	.375	.386	.397	.407	.418	.428	.438
.3	.448	.458	.468	.477	.487	.497	.506	.515	.525	.534

TABLE 5

Number to the One-Half Power Used to Obtain $s^{1/2}$ in Manning's Formula

No.	---0	---1	---2	---3	---4	---5	---6	---7	---8	---9
.00001	.003162	.003317	.003464	.003606	.003742	.003873	.004000	.004123	.004243	.004359
.00002	.004472	.004583	.004690	.004796	.004899	.005000	.005099	.005196	.005292	.005385
.00003	.005477	.005568	.005657	.005745	.005831	.005916	.006000	.006083	.006164	.006245
.00004	.006325	.006403	.006481	.006557	.006633	.006708	.006782	.006856	.006928	.007000
.00005	.007071	.007141	.007211	.007280	.007348	.007416	.007483	.007550	.007616	.007681
.00006	.007746	,007810	.007874	.007937	.008000	.008062	.008124	.008185	.008246	.008307
.00007	.008367	.008426	.008485	.008544	.008602	.008660	.008717	.008775	.008832	.008888
.00008	.008944	.009000	.009055	.009110	.009165	.009220	.009274	.009327	.009381	.009434
.00009	.009487	.009539	.009592	.009644	.009695	.009747	.009798	.009849	.009899	.009950
.00010	.010000	.010050	.010100	.010149	.010198	.010247	.010296	.010344	.010932	.010440
.0001	.01000	.01049	.01095	.01140	.01183	.01225	.01265	.01304	.01342	.01378
.0002	.01414	.01449	.01483	.01517	.01549	.01581	.01612	.01543	.01673	.01703
.0003	.01732	.01761	.01789	.01817	.01844	.01871	.01897	.01924	.01949	.01975
.0004	.02000	.02025	.02049	.02074	.02098	.02121	.02145	.02168	.02191	.02214
.0005	.02236	.02258	.02280	.02302	.02324	.02345	.02366	.02387	.02408	.02429
.0006	.02449	.02470	.02490	.02510	.02530	.02550	.02569	.02588	.02608	.02627
.0007	.02646	.02665	.02683	.02702	.02720	.02739	.02757	.02775	.02793	.02811
.0008	.02828	.02846	.02864	.02881	.02898	.02915	.02933	.02950	.02966	.02983
.0009	.03000	.03017	.03033	.03050	.03066	.03082	.03098	.03114	.03130	.03146
.0010	.03162	.03178	.03194	.03209	.03225	.03240	.03256	.03271	.03286	.03302
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05099	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07746	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1204	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.1811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3176	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302